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Seismic Evaluation and Retrofitting of Masonry Infill RCC Structures

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***Abstract*- Presence of infill walls in the frames alters the behavior of the building under lateral loads. However, it is common industry practice to ignore the stiffness of infill wall for analysis of framed building. Engineers believe that analysis without considering infill stiffness leads to a conservative design. But this may not be always true, especially for vertically irregular buildings with discontinuous infill walls. Hence, the modeling of infill walls in the seismic analysis of framed buildings is imperative. Indian Standard IS 1893: 2002 allows analysis of RCC buildings without considering infill stiffness but with a multiplication factor 2.5 in compensation for the stiffness discontinuity. Therefore, the objective of this paper is to study the effect of infill strength and stiffness in the seismic analysis of multi storey building. The analysis procedure is applied for the evaluation of existing design of a reinforced concrete bare frame, frame with infill and frame with infill and external shear wall. In order to examine the performance of these models, the Pushover analysis for seismic evaluation of existing buildings is performed. After performing the analysis retrofitting is suggested accordingly. Addition of shear wall as a retrofitting method is studied in this work. Also it is concluded that the effect of infill plays very crucial role in seismic evaluation of existing RC buildings. A detailed case study is reported.**

***Keywords*- Infill, Plastic hinge, retrofit, Pushover analysis.**

I. INTRODUCTION

Recent earthquakes in the Indian subcontinent have led to an increase in the seismic zoning factor over many parts of the country. Also, ductility has become an issue for all those buildings that were designed and detailed using earlier versions of the codes. Most recent constructions in the urban areas consist of poorly designed and constructed buildings. The older buildings, even if constructed in compliance with prevailing standards, may not comply with the more stringent specifications of the latest standards of IS 1893(Part 1):2002, IS 4326:1993 and IS 13920: 1993. The existing buildings can become seismically deficient since design code requirements are constantly upgraded due to advancement in engineering knowledge. Earthquakes cause damage to structural element as well as non structural element of building. Earthquake mainly affects structural components of lateral load resisting system. Earthquake produces massive stresses and deformation on structural member of building. Under such circumstances, seismic qualification of existing buildings has become extremely important. Seismic qualification eventually leads to retrofitting of the deficient structures.

For the design of a multi-storey framed structure. The load cases to be considered are the dead load, live load, seismic load, and their combinations. The input data that is normally fed into the computer software includes modulus of elasticity, Poisson’s ratio, density of concrete, areas and moments of inertia of all structural elements, zoning factor for seismic loading, and so on. Then one goes on to define the load combinations to obtain the worst load effects. Generally the gross section properties are used, and elastic analysis is performed. The design is based on the limit state philosophy. So the elastic load effects that are obtained are multiplied by the load factors to obtain the capacity requirements. It must be realized at this stage that when one attempts to carry out the seismic evaluation of a building, strictly speaking, the code provisions at the time of construction, age of the structure, construction practices etc., all become important.

The nonlinear static analysis procedures available termed as the Displacement Coefficient Method (DCM) included in the FEMA-356 document (FEMA, 2000), and the other termed as the Capacity Spectrum Method (CSM) included in the ATC-40 document (ATC, 1996). Both of these methods depend on the lateral load-deformation variation obtained by using the nonlinear static analysis under the gravity loading and idealized lateral loading due to the seismic action. This analysis is generally called as the pushover analysis.

Repair and retrofitting of concrete structures have been attracting the attention of researchers over the last two decades. Various repair/retrofit options available today include crack injection, shortcreting, steel jacketing, steel plate bonding, CFRP/GFRP jacketing, RC jacketing, addition of new structural elements (braces, walls, etc.), incorporation of passive energy dissipation devices, and provision of base isolation of local retrofitting. Repair and retrofit techniques can be used for enhancing the stiffness, strength, and ductility. In this study external concrete shear wall is provided to fulfill seismic requirement of building.

II. NEED FOR THE PRESENT STUDY

Assessment of the performance of the existing building requires accurate analysis of buildings considering infill stiffness and strength. The presence of infill walls in buildings accounts for the following issues:

- Increases the lateral strength and stiffness of the building frame
- Decreases the natural period of vibration
- Increases the base shear
- Increases the shear forces and bending moments in the ground storey columns.

There is a clear need to assess the design guidelines recommended by the IS code 1893:2002 based on accurate analysis.

III. STATIC PUSHOVER ANALYSIS

Pushover analysis is a technique by which a computer model of the building is subjected to a lateral load of a certain shape (i.e., parabolic, inverted triangular or uniform). In such analysis, a monotonic steadily increasing lateral load is applied to the structure, in the presence of the full gravity dead load, until a predetermined level of roof displacement is approached. The magnitude of lateral loads at floor levels do not affect the response of the structure in displacement-controlled pushover analysis, but the ratio in which they are applied at each floor level alters the response of the structures.

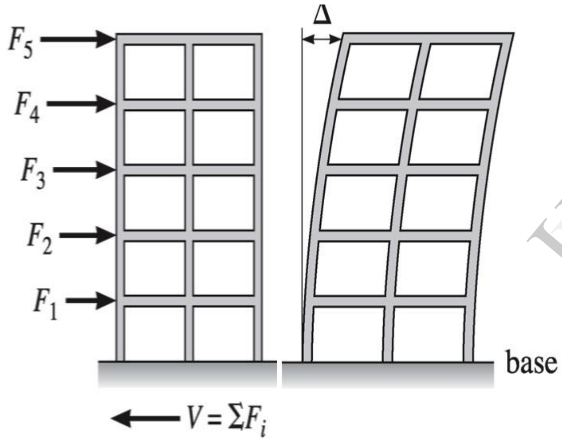


Fig.1 Static approximations in the pushover analysis

Pushover analysis is an efficient way to analyses the behavior of the structure, highlighting the sequence of member cracking and yielding as the base shear value increases. This information then can be used for the evaluation of the performance of the structure and the locations with inelastic deformation. The primary benefit of pushover analysis is to obtain a measure of over strength and to obtain a sense of the general capacity of the structure to sustain inelastic deformation.

The loads acting on the structure are contributed from slabs, beams, columns, walls, ceilings and finishes. They are calculated by conventional methods according to IS 456 – 2000 and are applied as gravity loads along with live loads as per IS 875 (Part II) in the structural model. The lateral loads and their vertical distribution on each floor level are determined as per IS 1893 – 2002 and calculated. These loads are then applied in "PUSH - Analysis case" during the analysis.

In this study capacity spectrum method (CSM) is used because it gives a visual representation of capacity-demand equation, suggests possible remedial action if the equation is not satisfied and easily incorporates several limit states, expressed as station on the load displacement curve of the structure.

The major steps of CSM are listed below,

1. Construction of General Response Spectrum
2. Transformation of General Response Spectrum into Demand Spectrum
3. Construction of Pushover Curve
4. Transformation of Pushover Curve into Capacity Spectrum
5. Determination of Performance Level on the basis of Performance Point

As per ATC 40 recommendations, the pushover analysis is applicable for this building. For pushover analysis, the beams and columns were modeled with concentrated plastic hinges at the column and beam faces, respectively. Beams have only moment (M3) hinges, whereas columns have axial load and biaxial moment (PMM) hinges. The moment-rotation relations and the acceptance criteria for the performance levels of the hinges were obtained from ATC-40. As the shear strengths of all the beams and columns were found to be more than the respective shear demands (from equivalent static and response spectrum methods), no shear hinge was modeled in the frame elements. The equivalent struts were modeled with axial hinges (entire length of the strut was considered as hinge length), that have a brittle load-deformation relation only for compression.

Pushover analysis was performed in presence of gravity loads, with monotonically increasing lateral loads, distributed according to the Code. Analyses were performed independently in the X and Y directions. To achieve life safety (LS) performance level under DBE, the target displacement at the roof was taken as 4 percent of the building height. The values of coefficients Ca and Cv determine is 0.16 and 0.22 respectively to model the design spectrum as per the Code. Geometric nonlinearity of the structure due to P-Δ effect was considered in the pushover analyses.

IV. MODELING OF INFILL WALL

The modeling of infill wall as an equivalent diagonal compression member was introduced by Holmes. The thickness of the equivalent diagonal strut was recommended as the thickness of the infill wall itself, and the width recommended as one-third of the diagonal length of infill panel.

The width of the strut using Airy's stress function was found to vary from d/4 to d/11 depending on the panel proportions. Later, a number of tests conducted by Smith (1966) proved that the equivalent strut width (w) is a function of relative stiffness (λh) of the frame and infill wall, strength of equivalent corner crushing mode of failure (Rc) and instantaneous diagonal compression in the infill wall (Ri).

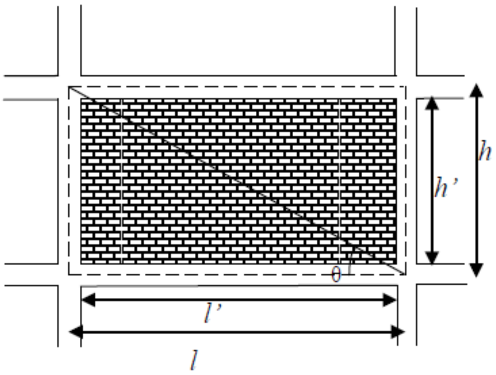


Fig.2 A typical panel of infilled frame

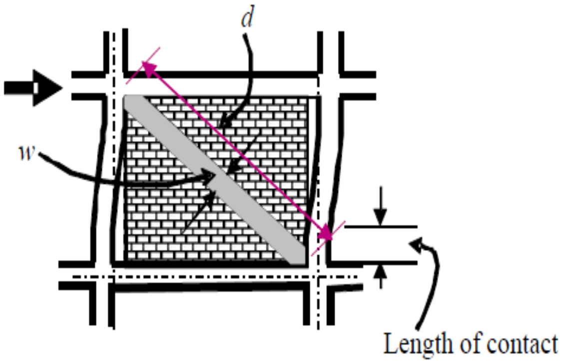


Fig. 3 Behavior of typical panel

This approach of modeling the struts is based on the initial stiffness of the infill wall. Fig.2 and Fig.3 shows how the infill panels behave when it is designed as equivalent diagonal strut when subjected to lateral load. Smith and Carter (1969) expressed the parameter, λh, as follows

$$\lambda h = \sqrt[4]{\frac{E_s t \sin 2\theta}{4E_c I_c h'}}$$

$$\frac{w}{d'} = 0.175(\lambda h)^{-0.4}$$

Where,
w =Width of strut without opening
λ =Stiffness reduction factor
E_s = elastic modulus of the equivalent strut
E_c = elastic modulus of the column in the bounding frame
I_c = moment of inertia of the column
h' = clear height of infill wall
h = height of column between centerlines of beams
t = thickness of infill wall
θ = slope of the infill wall diagonal to the horizontal
d' = is the clear diagonal length of the infill walls.

V. RETROFITTING METHOD OF ADDITION OF SHEAR WALL

The addition of shear walls to existing concrete frame buildings is a common retrofit technique. This technique is able to provide substantial increases in strength and stiffness for a building. However, it must also be recognized that the seismic forces will tend to be concentrated in the stiffest elements. The foundations may need to be strengthened accordingly and this is not always easily or inexpensively done.

It is one of method to increase lateral strength of the structure. New shear walls can be added to control drift. Critical design issues involved in the addition of shear walls are as follows.

- Transfer of floor diaphragm shears into the new wall through dowels.
- Adding new collector and drag members to the diaphragm.
- Reactions of the new wall on existing foundations.

In this study the retrofitting method of addition of shear wall is adopted. In the building external shear wall is located around the lift machine room therefore Life Safety (LS) performance level is achieved.

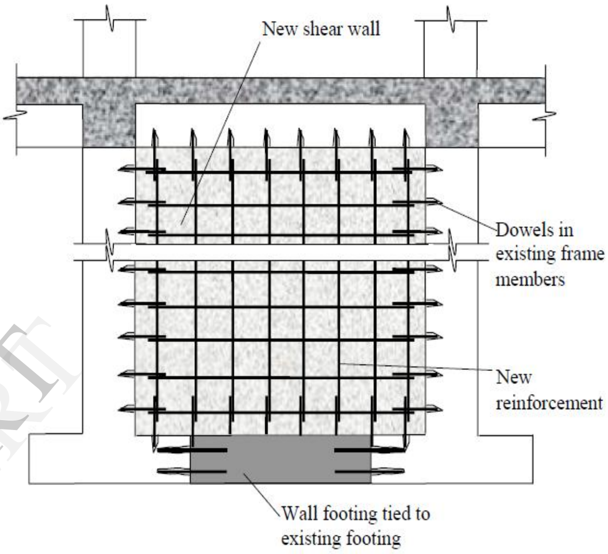


Fig.4 Addition of a shear wall (Courtesy: FEMA 172)

VI. DESCRIPTION OF THE STRUCTURE

Material properties:

M-20 grade of concrete and Fe-415 grade of reinforcing steel are used for all the frame models used in this study. Elastic material properties of these materials are taken as per Indian Standard IS 456: 2000. The modulus of elasticity (Ec) of concrete is taken as

$$E_c = 5000\sqrt{F_{ck}}$$

f_{ck} is the characteristic compressive strength of concrete cube in MPa at 28-day (20 MPa in this case). For the steel rebar, yield stress (f_y) and modulus of elasticity (E_s) is taken as per IS 456 (2000).

Structural elements:

Masonry infilled multi-storied RCC structures are modeled by 3D frame elements. The beam-column joints are modeled by giving end-offsets to the frame elements, to obtain the bending moments and forces at the beam and column faces. The beam-column joints are assumed to be rigid. The column end at foundation is considered as fixed for the models in this study. All the frame elements are modeled with nonlinear properties at the possible yield locations.

Building description:

An existing Residential building located at Amravati, India (Seismic Zone III) is selected for the present study. The building is fairly symmetric in plan and in elevation. This building is a G+3 storey building and is made of Reinforced Concrete (RC) Ordinary Moment Resisting Frames (OMRF). The concrete slab is 120mm thick at each floor level. The brick wall thicknesses are 150 mm for walls. Imposed load is taken as 4 kN/ m^2 for all floors. Fig.5and Fig.6 presents typical floor plans showing different column and beam locations.

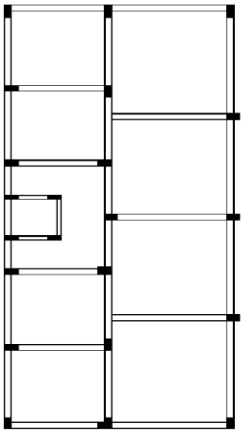


Fig.5 Parking floor plan

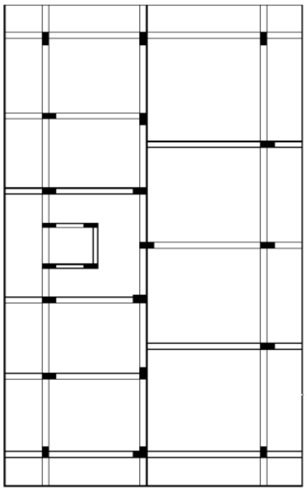


Fig.6 Typical floor plan

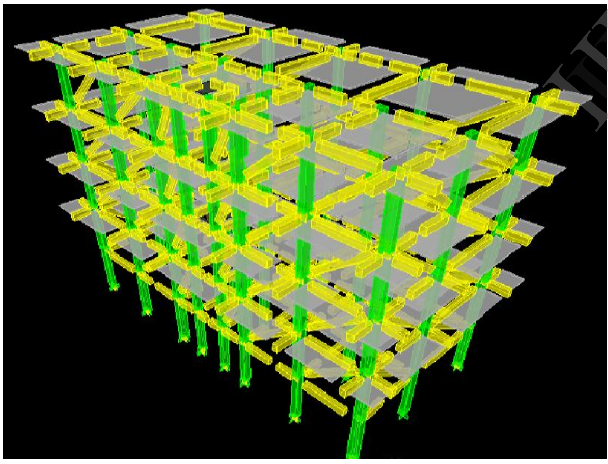


Fig.7 3D view of RCC Building with diagonal strut (masonry infill)

Structural details:

TABLE I NUMERICAL DATA

RC Frame Details	
1] Grade of concrete	20 N/mm^2
2] Grade of steel	415 N/mm^2
3] modulus of elasticity of concrete	22.36 kN/m^2
4] modulus of elasticity of steel	2x10^5 N/mm^2
5] unit weight of concrete	24 kN/m^3
6] Poisson's ratio	0.2
7] Sizes of beams	230x375,150x375mm,
8] Sizes of column	230x375,150x375mm,
Brick masonry Infill Details	
1] strength of brick masonry	4 N/mm^2
2] unit weight of masonry	20 kN/m^3
3] modulus of elasticity of brick masonry(550fm)	5000 N/mm^2
4] Thickness of peripheral wall	150mm
5] Poisson's ratio	0.16
6] Single strut model sizes	150x306mm, 150x388mm

VII. RESULTS AND DISCUSSION

Observation in X-direction and Y-direction

The deformed shapes and state of the nonlinear hinges at the performance point (Fig.12 to Fig.13) shows that the building will be damaged during the maximum considered earthquake. In X&Y-direction columns exceed the limit of Life safety as shown in Fig.12 and Fig.13. Structure response in term of floor displacements and frame resistance to base shear also shown in Fig.9 and Fig.10 during maximum considered earthquake.

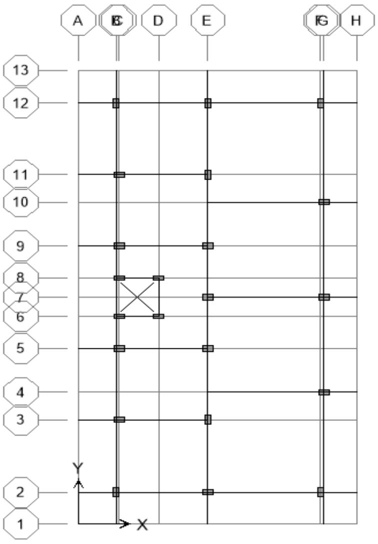
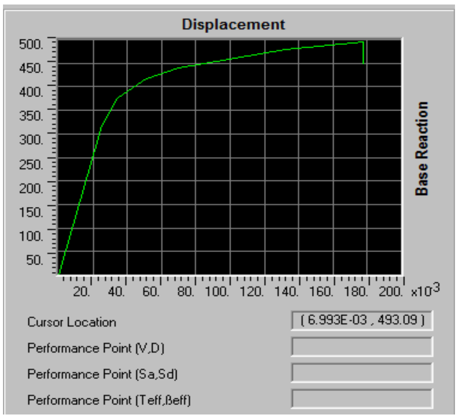
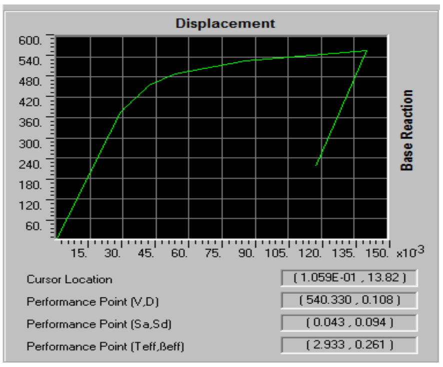


Fig.8 Plan without shear wall (before retrofitting)



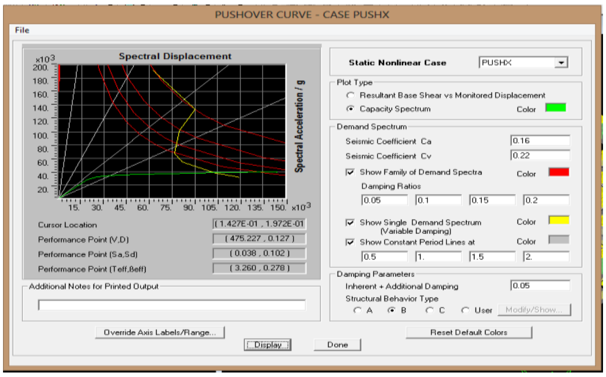
Cursor Location (6.993E-03 , 493.09)
Performance Point (V,D)
Performance Point (Sa,Sd)
Performance Point (Teff,Beff)

Fig.9 Plot of Base shear & Displacement(X-direction)



Cursor Location (1.059E-01 , 13.82)
Performance Point (V,D) (540.330 , 0.108)
Performance Point (Sa,Sd) (0.043 , 0.094)
Performance Point (Teff,Beff) (2.933 , 0.261)

Fig.10 Plot of Base shear & Displacement(Y-direction)



Cursor Location (1.427E-01 , 1.972E-01)
Performance Point (V,D) (475.227 , 0.127)
Performance Point (Sa,Sd) (0.038 , 0.102)
Performance Point (Teff,Beff) (3.260 , 0.278)

Additional Notes for Printed Output

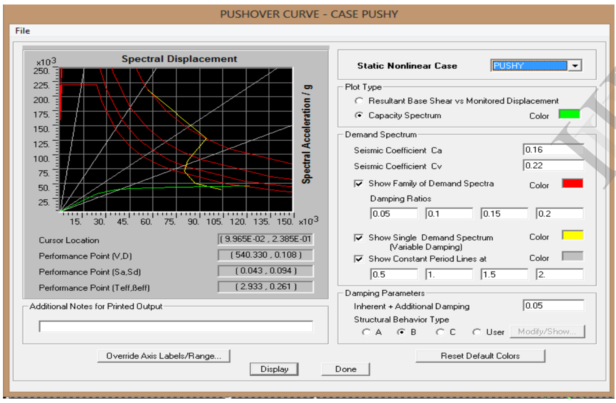
Static Nonlinear Case PUSHX

Plot Type
○ Resultant Base Shear vs Monitored Displacement
● Capacity Spectrum Color 🟩

Demand Spectrum
Seismic Coefficient Ca 0.16
Seismic Coefficient Cv 0.22
☑ Show Family of Demand Spectra Color 🟥
Damping Ratios 0.05 0.1 0.15 0.2
☑ Show Single Demand Spectrum (Variable Damping) Color 🟨
☑ Show Constant Period Lines at Color ▨
0.5 1. 1.5 2.

Damping Parameters
Inherent + Additional Damping 0.05
Structural Behavior Type ○ A ● B ○ C ○ User

Fig.11 Pushover curve(X-direction) before retrofitting



Cursor Location (9.965E-02 , 2.385E-01
Performance Point (V,D) (540.330 , 0.108)
Performance Point (Sa,Sd) (0.043 , 0.094)
Performance Point (Teff,Beff) (2.933 , 0.261)

Additional Notes for Printed Output

Static Nonlinear Case PUSHY

Plot Type
○ Resultant Base Shear vs Monitored Displacement
● Capacity Spectrum Color 🟩

Demand Spectrum
Seismic Coefficient Ca 0.16
Seismic Coefficient Cv 0.22
☑ Show Family of Demand Spectra Color 🟥
Damping Ratios 0.05 0.1 0.15 0.2
☑ Show Single Demand Spectrum (Variable Damping) Color 🟨
☑ Show Constant Period Lines at Color ▨
0.5 1. 1.5 2.

Damping Parameters
Inherent + Additional Damping 0.05
Structural Behavior Type ○ A ● B ○ C ○ User

Fig.11 Pushover curve(Y-direction) before retrofitting

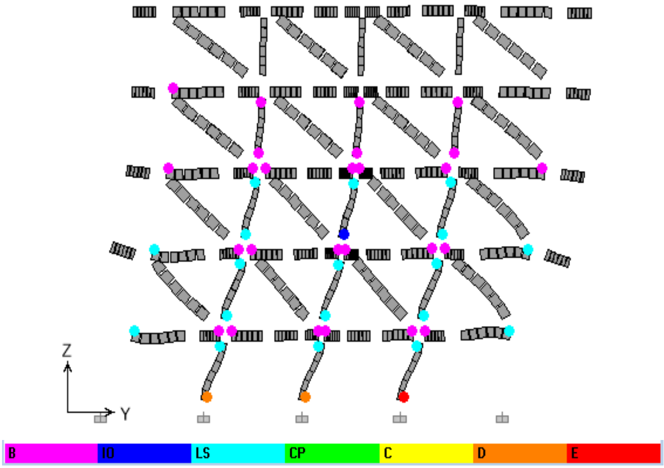


Fig.12 Elevation view-G Deformed shape (PUSHY) before retrofitting

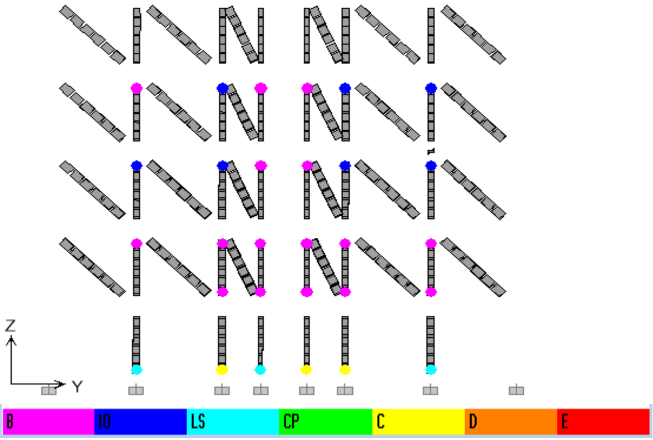


Fig.13 Elevation view-C Deformed shape (PUSHX) before retrofitting

Conceptual retrofitting scheme

As observed from nonlinear static analysis structure have few columns which are not meeting the criteria of life safety in Y-direction so to enhance the capacity of structure external shear wall around the lift machine room is added conceptually in it, location of RCC walls and relevant detailing shown in Fig.14. This RCC wall is basically replaced the existing ordinary masonry walls, so that the same 3-D model is used with strengthened infill walls, modelled with linear compression struts and tensions ties. Results of revised model are as under

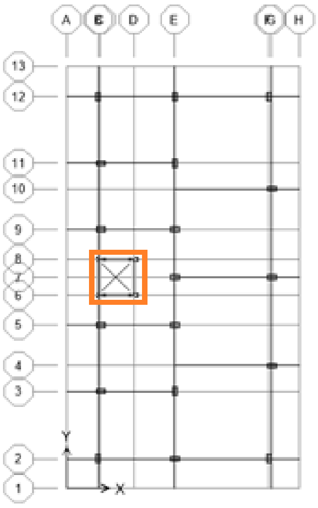
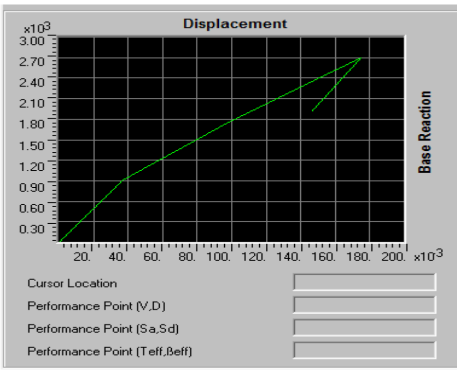
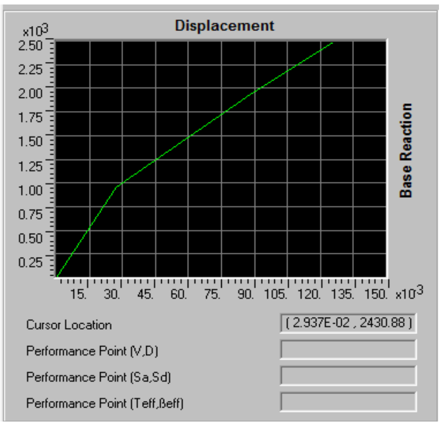


Fig.14 Plan with shear wall



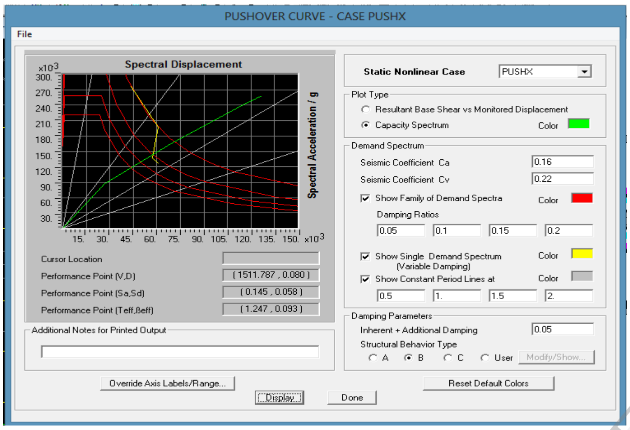
Cursor Location
Performance Point (V,D)
Performance Point (Sa,Sd)
Performance Point (Teff,Beff)

Fig.15 Plot of Base shear & Displacement(X-direction)



Cursor Location (2.937E-02 , 2430.88)
Performance Point (V,D)
Performance Point (Sa,Sd)
Performance Point (Teff,ßeff)

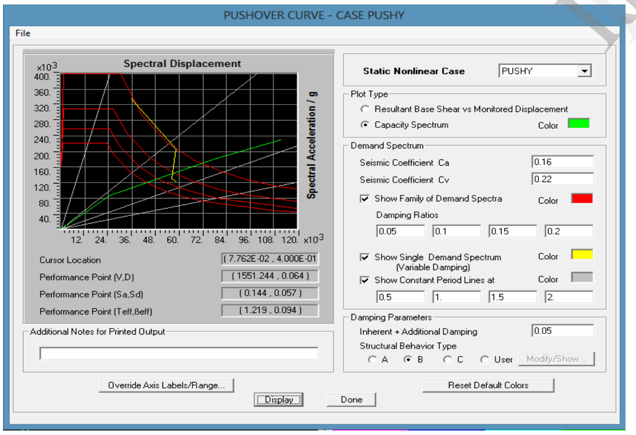
Fig.16 Plot of Base shear & Displacement(Y-direction)



Cursor Location
Performance Point (V,D) (1511.787 , 0.080)
Performance Point (Sa,Sd) (0.145 , 0.058)
Performance Point (Teff,ßeff) (1.247 , 0.093)
Additional Notes for Printed Output

Static Nonlinear Case PUSHX
Plot Type
○ Resultant Base Shear vs Monitored Displacement
● Capacity Spectrum Color 🟩
Demand Spectrum
Seismic Coefficient Ca 0.16
Seismic Coefficient Cv 0.22
☑ Show Family of Demand Spectra Color 🟥
Damping Ratios 0.05 0.1 0.15 0.2
☑ Show Single Demand Spectrum (Variable Damping) Color 🟨
☑ Show Constant Period Lines at Color ⬜
0.5 1. 1.5 2.
Damping Parameters
Inherent + Additional Damping 0.05
Structural Behavior Type ○ A ● B ○ C ○ User

Fig.17 pushover curve(x-direction) after retrofitting



Cursor Location (7.762E-02 , 4.000E-01
Performance Point (V,D) (1551.244 , 0.064)
Performance Point (Sa,Sd) (0.144 , 0.057)
Performance Point (Teff,ßeff) (1.219 , 0.094)
Additional Notes for Printed Output

Static Nonlinear Case PUSHY
Plot Type
○ Resultant Base Shear vs Monitored Displacement
● Capacity Spectrum Color 🟩
Demand Spectrum
Seismic Coefficient Ca 0.16
Seismic Coefficient Cv 0.22
☑ Show Family of Demand Spectra Color 🟥
Damping Ratios 0.05 0.1 0.15 0.2
☑ Show Single Demand Spectrum (Variable Damping) Color 🟨
☑ Show Constant Period Lines at Color ⬜
0.5 1. 1.5 2.
Damping Parameters
Inherent + Additional Damping 0.05
Structural Behavior Type ○ A ● B ○ C ○ User

Fig.18 Pushover curve(Y-direction) after retrofitting

The retrofitting method of addition of shear wall is adopted. In the building external shear wall is located around the lift machine room therefore Life Safety (LS) performance level is achieved (Fig.19 and Fig.20)

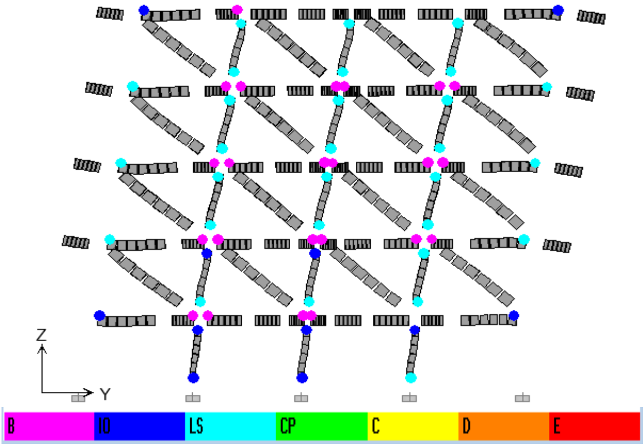


Fig.19 Elevation view-G Deformed shape (PUSHY) after retrofitting

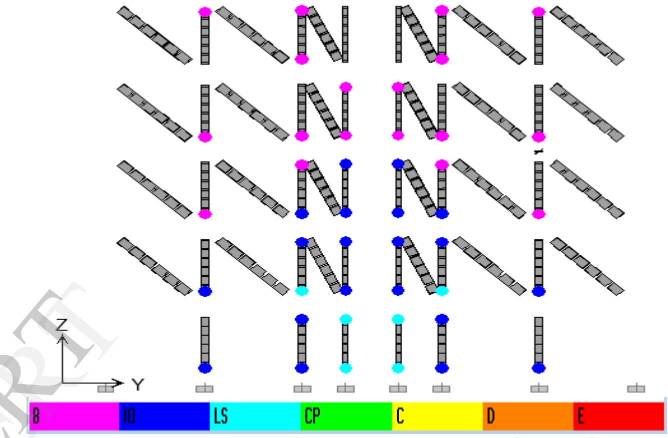


Fig.20 Elevation view-C Deformed shape (PUSHX) after retrofitting

After retrofitting it was observed from analysis structure satisfy the Life Safety criteria. Improvement in structure performance clearly observed through results shown below from table II. In Fig.17 and Fig.18 pushover curves after retrofitting In x and y direction is shown, in Fig.19 and Fig.20 structure deformed shape shown at performance point now all columns are meeting the criteria of Life Safety.

In Fig.21 and Fig.22 floor displacements are shown before and after retrofitting of structure.

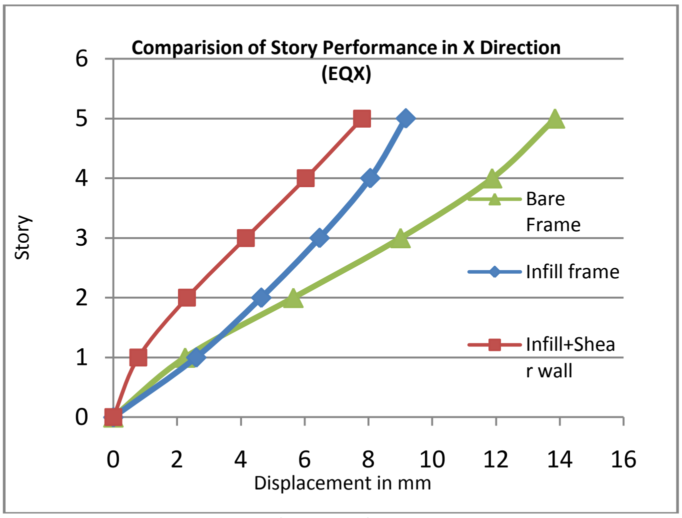


Fig.21 Comparison of story performance in X-direction

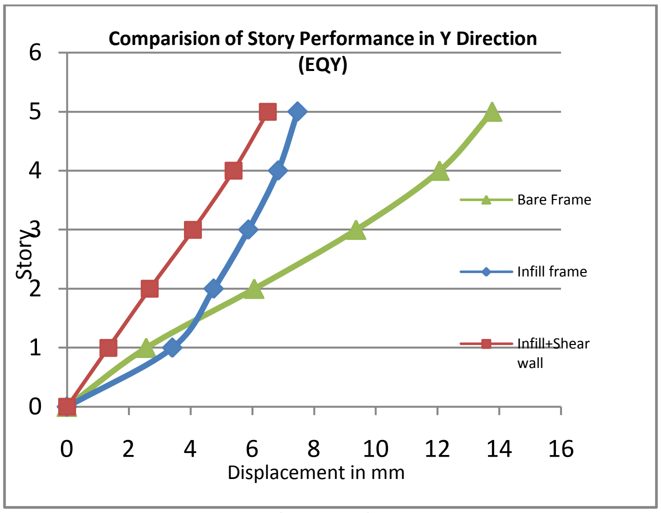


Fig.22 Comparison of story performance in Y-direction

Summary

TABLE II PERFORMANCE OF BUILDING BEFORE & AFTER RETOFITTING

→	Displacement (in m)		Shear (in KN)		Spectral acceleration (in m/s^2)		Spectral displacement (in m)	
↓	X-dir	Y-dir	X-dir	Y-dir	X-dir	Y-dir	X-dir	Y-dir
Before retrofitting	0.127	0.108	475.22	540.33	0.038	0.043	0.102	0.094
After retrofitting	0.080	0.064	1511.78	1551.24	0.145	0.144	0.058	0.057

VIII. CONCLUSIONS

The whole study is concentrated on seismic evaluation and retrofitting of existing RC building. Seismic analysis is carried out for existing reinforced concrete building. After all the study the following conclusions are drawn

- Results indicate that infill panels have a large effect on the behavior of frames under earthquake excitation. In general, infill panels increase stiffness of the structure.
- Result indicates approximately 50% reduction in maximum displacement for infill masonry as compare to without infill.
- From the result it is observed that due to infill effect stiffness of the frame increases and due to which comparatively less reinforcement is required as compared to reinforcement required in bare frame to resist maximum considered earthquake.
- It is concluded that addition of external concrete shear wall increases the base shear of the building 3 times of building which is without shear wall, and therefore it is effective and economical method for improving the seismic resistance capacity of the member and building as well.

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